RETURNS TO FARM-LEVEL SOIL CONSERVATION ON TROPICAL STEEP SLOPES: THE CASE OF THE ERITREAN HIGHLANDS

by
B. Araya and J. Asafu-Adjaye

No. 253
April 1999

PUBLICATIONS IN THE *ECONOMICS CONFERENCE MONOGRAPH SERIES* OF THE DEPARTMENT OF ECONOMICS

No 1 *Bangladesh: Economy, People and the Environment*
(Editors: M. Alauddin and S. Hasan), pp.xx + 403

No 2 *China's Economic Growth and Transition*
(Editors: C.A. Tisdell and J.C.H. Chai), pp.viii + 526

No 3 *China and the Asia Pacific Economy*
(Editors: J.C.H. Chai, Y.Y. Kueh and C.A. Tisdell), pp.viii + 467

No 4 *Evolving communication and Socio-Economic Change: STEP 1996*
(Editors: D. Anthony, T. Mandeville and J. Foster), pp.iv + 108

No 5 *Fifty Years of Indian Development: India in Retrospect, Future Directions and Investment Outlook*
(Editors: P.K. Basu, N.D. Karunaratne and C.A. Tisdell), pp.xiii + 170.

No 6 *Facets of Development of Sri Lanka Since Independence: Socio-Political Economics, Scientific and Cultural*
(Editors: W.D. Lakshman and C.A. Tisdell), **forthcoming**.

The above titles are available at very reasonable prices while stocks last.

Note: The Department of Economics also publishes a *Discussion Papers* series, which consists usually of more technical papers. Details are available from the Publications Officer at the address below with whom orders may also be placed for both *Discussion Papers in Economics* and the *Economics Issues* series.

Publications Officer
Department of Economics
The University of Queensland
Brisbane Q 4072 Australia
Phone: 61 7 3365 6570
Facsimile: 61 7 3365 7299
Email: enquiries@economics.uq.edu.au

Address:	Department of Economics University of Queensland Queensland 4072 Australia	**Telephone:** **Fax:** **Email:**	(07) 33656570 (07) 33657299 enquiries@economics.uq.edu.au

The Department of Economics has developed specialisations in several fields of applied economics including project evaluation and cost benefit analysis, transport economics, public finance, regional and urban studies, applied econometric analysis and economic model building. Other areas of interest to the Department include development economics, natural resource utilisation, environmental economics, science and technology policies, information economics research, macroeconomics and monetary economics.

CONSULTING SERVICES:

* economic impact analysis at state and regional level
* regional and urban economic planning and policy issues
* local government economic planning
* general microeconomic analysis
* industry studies
* health services research
* economic evaluation studies
* cost benefit analysis
* economic modelling and testing
* macroeconomic forecasting
* statistical package instruction
* economic analysis of Queensland economy and Queensland economic policy
* natural resource and environmental economics including marine resource economics and aquaculture
* labour economics
* science technology and information policy
* information economics and economics of technological change
* input-output impact studies
* managerial economics
* economics of tourism
* development economics in the Third World - Asian Pacific Economics

Research units within the Department include:

Regional and Urban Economics Research Unit *(Director: Professor Rod Jensen)*
This unit was formed to co-ordinate activities appropriate to research and the dissemination of ideas on regional and urban economics. The Unit has particular strengths in regional and urban modelling, policy and planning.

Resources Environment and Development Research Unit *(Director: Dr. George Docwra)*
This unit was formed to carry out research into all aspects of economic and environmental policy formation with particular, but not exclusive, focus on Queensland and Australia, centring on issues which involve natural resources.

Queensland Economic Policy Research Group *(Director: Dr. Tom Riha)*
The program is concerned with research into any aspect of Queensland economy - but especially with critiques of government policy, restructuring of the economy in the light of changing world trade circumstances, public finance, and aspects of federalism.

RETURNS TO FARM-LEVEL SOIL CONSERVATION ON TROPICAL STEEP SLOPES: THE CASE OF THE ERITREAN HIGHLANDS

Bereket Araya and John Asafu-Adjaye[1]

Department of Economics
The University of Queensland
Brisbane Qld 4072
Australia

Discussion Paper No 253

April 1999

ISSN 1033-4661

[1] The authors are, respectively, with the Department of Economics, University of Asmara, Eritrea and Department of Economics, The University of Queensland, Brisbane, Qld 4072, Australia. All correspondence should be directed to John Asafu-Adjaye; fax: 61-7-3365-7299; email: j.asafu-adjaye@economics.uq.edu.au.

RETURNS TO FARM-LEVEL SOIL CONSERVATION ON TROPICAL STEEP SLOPES: THE CASE OF THE ERITREAN HIGHLANDS

Abstract

This study conducts an economic analysis of investment in simple soil conservation technologies in the highlands of Eritrea. The data used in the analysis were obtained from a farm survey and supplemented with data from secondary sources. Risk analysis techniques are used to take account of the uncertainties regarding the relationship between soil erosion and crop yield. The financial analysis reveals negative net present values (NPVs) and internal rates of return (IRRs) below 12 percent for various slope categories. On the other hand, the economic analysis returns positive NPVs and IRRs of over 20 percent. The results clearly indicate that investment in soil conservation technology may not be a viable short-term proposition from the farmer's point of view and yet the net social benefits are positive. There is a strong case for government to provide incentives for soil conservation in view of the economic benefits.

Keyword(s): Eritrea, soil conservation, cost-benefit analysis, risk analysis

1. Introduction

Eritrea is a relatively new African country, which gained independence in 1993 after a long civil war with neighbouring Ethiopia[1]. Eritrea has an estimated population of 2.7 million. In general, there is a lack of reliable economic indicators on the performance of the Eritrean economy due to the disruptions caused by the civil war. Eritrea has potential mineral and petroleum resources and there are also significant marine resources that are yet to be exploited. However, agriculture is the mainstay of the Eritrean economy, providing employment for about 80 percent of the labour force and contributing about 26 percent of the country's gross domestic product (GDP).

Land degradation, in particular, soil erosion is a serious environmental problem facing Eritrea today. The problem is caused by natural as well as human factors. The natural causes include highly erosive rainfall patterns and ragged topographical feature. Since the soils in the highlands of Eritrea are generally shallow and of low fertility they produce poor vegetative cover. In addition, most of the soils have low organic content which reduces their moisture storage capacity and infiltration rate. These characteristics of the soils have been instrumental in causing soil erosion in the region. The human causes of soil erosion in the region include deforestation, overgrazing and inappropriate agricultural practices such as extension of croplands to environmentally fragile steep slopes. Other human causes are indirect and include factors such as insecure land tenure arrangements, population growth, poverty and war. These factors affect the willingness and ability of farmers to undertake long term investment in soil conservation.

Several commentators are of the view that estimates of the rates of soil erosion in Africa are often overstated. Such errors arise mainly from the complex nature of soil erosion which, in turn, gives rise to methodological problems. However, notwithstanding the inaccuracies, aid agencies and government departments have used these data to make predictions and inform policy. For example, a 1984 FAO report asserted that soil erosion and organic matter loss in Northern Ethiopia was reducing crop yields by two percent per annum (FAO, 1984). The same report estimated that by 2010 the land incapable of supporting agriculture would increase from two million to ten million hectares, an area equivalent to 17 percent of the Ethiopian highlands. After the 1985 famine, the International Fund for Agricultural Development (IFAD) designated Ethiopia (of which Eritrea was then a part) as the worst case of land degradation in sub-Saharan Africa (IFAD, 1986).

Recently, writers on the subject of land degradation in Africa have taken a critical look at analyses and projections on the problem (e.g., Hoben, 1996; Stocking, 1996). It has been suggested that the neo-Malthusian predictions of impending environmental catastrophe have been used to justify massive aid projects. In the case of Ethiopia, the World Food Program (WFP) supplied aid to the tune of about $US116 million in Food for Work (FFW) assistance specifically for soil and water conservation programs from 1979 and 1992 (World Bank, 1994). During this period, more than one million km of soil and stone bunds on agricultural land and more than 500,000 km of terraces were constructed on hillsides.

To date, the soil and water conservation programs have resulted in failure. Many of the conservation structures that were put up have fallen into a state of disrepair and farmers have been unwilling to undertake maintenance of their own accord. Ex post evaluations of the projects list various reasons for the failure of the programs. These include an authoritarian and top-down approach and failure to take account of farmers' needs and concerns (Yeraswork, 1988, cited in Stocking, 1996). In general, these programs failed to build on indigenous conservation knowledge and did not give serious consideration to factors likely to affect the adoption of the new technology.

There is a need for more site-specific studies of the soil conservation problem in order to devise more effective policy responses. The nature and extent of the problem vary across countries and across different parts of the same country depending on the history of land use in the area, the type of soil, landforms, climatic factors and other social, political and economic factors. The extent of damage from soil erosion depends on a number of factors including soil depth, soil texture, and quality of subsoil. For example, a substantial loss of topsoil from initially deep soils or from areas where the subsoil is fertile may have little impact on crop compared to the yield loss from the same levels of erosion from initially shallow soils. Therefore, the benefits of soil conservation measures will vary from place to place, depending on the potential rate of erosion and the erosion-yield relationship.

The cost of undertaking conservation measures will also vary for different areas depending on the availability of labour and other inputs as well as the physical characteristics of the cropland (which determine the requirements for labour and other materials). Thus, high rates of soil erosion, *per se*, may not necessarily justify investment in soil conservation measures. The benefits from soil conservation should therefore be carefully weighed against the costs. Another important aspect of the soil conservation problem is that the benefits are dispersed over time and space. For example, the benefits of controlling erosion may not necessarily be realised within the planning period of the farmer. In this respect, the social benefits of investment in soil conservation technologies may diverge from the private benefits. Since soil conservation measures may generate benefits to the society but may actually impose short-term costs on the farmer, rational (profit or income-maximising) behaviour of farmers might induce them to under-invest in soil conservation activities.

This paper uses discounted flow (DCF) analysis to estimate the private and social costs and benefits of soil conservation measures in the Afdeyu Catchment of the Eritrean highlands. The data for this analysis were obtained from a field survey undertaken in Eritrea from September 1995 to February 1996. These data were supplemented with secondary data gathered at the Afdeyu Research Station. A modified version of the Universal Soil Loss Equation (USLE) (Hurni, 1988) is used to estimate the rate of soil loss for various slope categories[2]. This information is combined with experimental data to estimate the relationship between crop yield and soil loss in the study area. The data generated are then used to estimate the net incremental benefits of soil conservation. Given the uncertainties regarding the rate of erosion and the erosion-yield relationship, risk analysis techniques are used to generate the DCF measures.

The paper proceeds as follows. Section 2 discusses issues relating to the economics of the soil conservation problem. Following a brief description of the study area in Section 3, Section 4 outlines the methodology used in estimating the costs and benefits of soil conservation measures. The main findings of the analysis are presented in Section 5, while Section 6 concludes with the policy implications.

2. The Economics of Soil Conservation

Estimating the benefits and costs of investment in soil conservation is a difficult undertaking due to the complexity of the factors involved. On the benefits side, soil is rarely traded as an agricultural input and therefore it is difficult to value soil erosion. It has been suggested that the market for land can be used as a proxy for the market for soil (McConnell, 1983; Miranowski and Hammes, 1984; Hertzler *et al.,* 1985). Theoretically, soil erosion reduces the future productivity of a piece of land and thus reduces its price. It has been suggested that if there is a functioning market for land, the price of land transmits a correct signal regarding the effects of erosion on present as well as future productivity. However, in reality, even when there is a functioning land market, the cost of soil degradation may not be accounted for in land prices due to lack of information. Studies by Ervin and Mill (1985) and Gardner and Burrows (1985) conclude that farm prices do not adequately reflect erosion damage.

An economic analysis of soil conservation involves the identification of the costs and benefits from the perspective of the farmer as well as that of the society. Four main factors could complicate this type of analysis. These are: 1) quantifying the magnitude of the rate of erosion; 2) estimating the impact of erosion on crop productivity in different time periods; 3) weighing the relative importance of present and future benefits (i.e. the choice of an appropriate discount rate); and 4) valuing some of the qualitative costs and benefits. Each of these factors has its own complications. For example, there is lack of reliable data on soil loss in most developing as well as developed countries. The problem is complicated by the fact that soil loss does not necessarily mean lost production since the soil could be re-deposited in another location. The relationship between soil loss and crop yield is complex and is often obscured by other factors[3]. Furthermore, soil erosion imposes external costs such as water pollution, sedimentation of dams and damage to downstream crops which further complicates the valuation process.

3. Description of the Study Area

The study area, Afdeyu Catchment, was selected to represent the low potential cropping zone of the highlands of Eritrea. The choice of Afedyu catchment was also influenced by the relative availability of data on soil loss and runoff as well as topographic and climatic data from the Afdeyu Research Station, which is located in the catchment. The research station is located about 22 km north of Asmara, the capital of Eritrea. The station monitors a catchment area of 180 ha most of which belongs to the Afdeyu village. The station was established in 1984 by the Ethiopian Soil Conservation Research Project (SCRP). The main purpose of the station is to measure soil loss and runoff from research plots, gather meteorological data, and collect harvest samples from farmers' croplands.

The major agricultural activities in Afdeyu, as in most parts of the highlands of Eritrea, involve crop and livestock production. Croplands account for more than 76 percent of the catchment, while grassland and forest areas account for about 5.6 and 0.3 percent respectively (see Table 1). Rock areas, which account for 14 percent of the catchment, are not suited for any kind of agricultural activity due to their shallow soils. The considerable proportion of bare rock in the catchment, combined with the high proportion of shallow soils unsuitable for agricultural production, could be the result of uncontrolled land degradation in the highlands of Eritrea, in general, and the Afdeyu Catchment, in particular. The area represented as 'forest' in Table 1 mainly comprises eucalyptus trees (an introduced species), the catchment being almost entirely devoid of natural vegetation.

Table 1 Land Use Categories in the Afdeyu Catchment, 1985

Type of land cover	Area (ha)	Percentage of Catchment
Rock Area	25.2	14.0
Grassland/forested	9.9	5.5
Town Area	6.9	3.8
Fallow	7.7	4.3
Cultivated land	129.7	72.1
Total	180.0	100.0

Source: SCRP (1991).

The Afdeyu Research Station regularly measures soil loss and runoff on four experimental plots in the catchment. Based on data taken from the experimental plots, and using the USLE adapted for the Ethiopian highlands, rates of soil loss for the catchment according to slope category have been estimated[4]. The results (Table 2) suggest that the rate of soil loss from croplands vary strongly with slope. While croplands with gentle slopes (0-8%) lose a little more than 7 tonnes per ha per year, steeper land (more than 30%) suffer a loss of more than 79 tonnes per ha per year. The average soil loss from the catchment's croplands is estimated at 18.8 tonnes per ha per year.

Table 2 Estimated Rates of Soil Loss in the Afdeyu Catchment (By Slope Groups)

Slope Category	Soil loss (t/ha)	Runoff (mm/ha)
A: 0-8 %	7.1	46.1
B: 8-16%	28.3	183.9
C: 16-30 %	53.6	348.3
D: 30-45 %	79.7	517.9

Source: Authors' calculations.

4. Estimating the Costs and Benefits of Soil Conservation Measures

Soil erosion from agricultural lands imposes both on-site and off-site costs on society. On-site costs include decline in crop yield (and biomass) as well as loss of productive agricultural land. The off-site costs, on the other hand, arise from problems such as sedimentation of dams and other water bodies, and physical damage of downstream crops by floods from uncontrolled runoff and so on. The on-site costs of soil erosion on croplands arise from: 1) a decline in crop yield; 2) a decline in crop area as soil depth of some areas decreases beyond the minimum level required to support crop production; and 3) a decline in the number (or size) of livestock, because the production of crop residue available for stock feed also decreases with the decline in crop yield. Therefore, the benefits of undertaking soil conservation measures include a reduction in soil erosion and avoidance of the above costs, as well as increase in crop and livestock production through conservation's moisture-conserving effect. On the other hand, the costs of undertaking soil conservation measures include expenditures on labour and tools for construction and maintenance of soil conservation structures, and loss of potential crop production from areas occupied by the structures.

There are three main types of soil conservation structures in use in the catchment area: stone and soil bunds; *fanya-juu* and double ditch. *Fanya-juu* is a Swahili word meaning "throwing up slope'. It is an indigenous method of conservation involving the construction of a basin on the lower side of a bund and a soil or stone embankment on the upper side. The double ditch is similar to *fanya-juu* except that the bund is constructed between two ditches. The cost estimates in this study are based on stone and soil bunds because they are the commonest structures in the study area.

The variables which affect crop yield, include soil depth, rainfall, soil type and the crop management system practised (e.g. number of weedings, number of ploughings, crop rotation and fertiliser use). Of these, reliable measurements are available only for soil depth, rainfall and yield. Estimates of the erosion-yield relationships for crops and fodder were obtained by regressing yield on soil depth and rainfall. The data were obtained from Afedyu Research Station's records for the period 1987-1995. For both barley and wheat, the response of crop and fodder yield to soil depth has been calculated as a weighted average of the coefficients of the respective soil depth variables, with the weights equivalent to the areas of barley and wheat under cultivation in the catchment. The results are reported in Table 3. In general, there is a significant positive relationship between crop yield, on the one hand, and soil depth and rainfall, on the other.

Table 3 Estimated Crop and Fodder Yield Functions[a,b]

Independent Variable	Crop Yield		Fodder Yield	
	Barley	Wheat	Barley	Wheat
Constant	0.31	-0.31	0.80	0.39
Soil depth	0.32	0.02	0.09	0.07
	(1.74)	(1.40)	(1.08)	(2.05)
Rainfall	0.003	0.004	0.007	0.005
	(2.68)	(5.98)	(0.28)	(2.92)
R^2	0.10	0.37	0.03	0.17
F	4.9*	19.8*	1.7	7.02*
N	94	64	94	74

a. The dependent variable is yield in t/ha; soil depth is measured in centimetres and rainfall in millimetres.
b. t-ratios are in parentheses.
* Significant at the 1% level.

Cost of Soil Conservation Structures

The costs of establishing soil conservation structures include: 1) labour costs; 2) costs of tools and materials; and 3) opportunity cost of crops foregone on land occupied by conservation structures. For purposes of this study the cost of undertaking soil conservation measures is limited to the costs involved in erecting stone and soil bunds, since they are the dominant conservation structures in the catchment. The cost of installing these structures per unit area depends on the horizontal spacing of the structures which, in turn, depends on the slope of the land. The materials required for construction of the bunds are readily available and have few alternative uses. Therefore, the material cost is assumed to be zero. Construction of these structures is labour intensive. The labour cost of constructing stone bunds is estimated to be Birr 669.00 per ha for slope Category A (0-8%), rising to Birr 3847 per ha for slope Category C (16-30%)[Appendix 1].

The opportunity cost of labour is estimated by the cash value of food earned from FFW programs, which is currently about Birr 7.5-8.00 per person per day (Riely, 1995:33). Simple tools such as mattocks and shovels are commonly used to construct stone bunds. The cost of tools is estimated at Birr 60 per ha. Maintenance costs are zero in the first year of construction but rise in Year 2 to Birr 36 per ha for a Category A slope and to Birr 195 per ha for a Category

C slope. These costs are assumed to decline by 20 percent per annum after the second year. Therefore, the total estimated costs in Year 1 range from Birr 729 per ha for a Category A slope farm to Birr 3907 per ha for a Category C slope farm (see Appendix 1).

Financial Benefits of Soil Conservation

Due to data limitations, estimation of the benefits of undertaking soil conservation practices in this study is restricted to the values of increased yield and increased fodder production. Yield estimates for the catchment, based on the above methodology, are 1.67 tons/ha and 3.20 tons/ha for crops and fodder, respectively. In calculating the change in the value of crop yield due to soil conservation, allowance is made for the loss of output from the land occupied by the structures. This is estimated to range from 3 percent for Category A to 21 percent for Category C. The value of fodder is derived on the basis of the number of Tropical Livestock Units (TLU's) that can be supported by one tonne of fodder. The value of a tonne of fodder is estimated to be Birr 99.60[5]. With soil conservation, crop yield is assumed to increase by 10, 34 and 54 percent per annum for Category A, B, and C slope land, respectively. Fodder yield is a little lower, ranging from 10 percent to 38 percent for the three slope types (see Appendix 1).

Derivation of Economic Costs and Benefits

For the economic analysis the market prices are adjusted to better reflect opportunity costs. Currently, the price of bread is subsidised in order to provide the urban population with access to low-cost food, and to reduce use of fuelwood which would otherwise be needed to prepare bread and *injera* for domestic use (Riely, 1995:40). The government of Eritrea monetises food aid wheat in order to finance the bread subsidy. Thus, the market price of wheat does not reflect its scarcity valued. A weighted average of the import parity prices of wheat and barley are used to arrive at an economic price of Birr 2047 per metric tonne.

As in most developing countries, the rural wage in Eritrea does not provide an accurate reflection of the opportunity cost of shifting from one occupation to another. Although it is reasonable to assume that the daily wage of unskilled labour reflects the marginal value product (MVP) of labour in the peak agricultural season when almost all farmers and their families are fully employed, this assumption is not realistic for the remainder of the year. A social discount factor for unskilled labour is obtained by calculating the ratio of the mean number of days farmers spend in on-farm employment to the total number of days in the off-peak season; this ratio is 99/180 or 0.55. This factor is applied to the going rural wage of Birr 7.50 per day to arrive at a shadow wage rate of Birr 4.26 per day.

Financial and Economic Analysis

Returns to soil conservation measures are estimated from the farmer's point of view (financial analysis) and from society's point of view (economic analysis). In comparing the *with* and *without* soil conservation scenarios, only the incremental costs and benefits associated with soil conservation are considered. The net benefits are the difference in the cash flows of these two scenarios.

The choice of discount rate is a controversial topic in the literature. Many environmentalists argue against discounting, in general, and high discount rates, in particular, because they believe high discount rates are associated with environmental degradation (Goodin, 1982). The high discount rates are thought to be a cause of degradation because individuals prefer short-term measures to satisfy immediate needs, and at the expense of environmental conservation (Pearce, 1987; Pearce and Markandya, 1990). In the case of developing countries, it is often assumed that there is a vicious circle between poverty and environmental degradation. That is, high discount rates cause environmental degradation, which, in turn, worsens poverty and further increases discount rates. However, the adverse impacts of high discount rates on environmental quality have not been established beyond doubt. For example, it is possible that demand for natural resources could be lower at high discount rates (see Krautkraemer 1985 for a proof). Furthermore, there have been instances where people facing imminent danger have taken decisions with long-term implications for their (or their family's) survival. In view of the uncertainty regarding the social rate, a real discount rate of 12 percent and a planning period of 25 years are used in this study. This rate is the average of discount rates published by the International Monetary Fund (International Financial Statistics) for Ethiopia for the period 1987 to 1995.

The decision criteria employed to evaluate the returns to investment in soil conservation are the net present value (NPV) and the internal rate of return (IRR) [Gittinger, 1982]. In view of the uncertainties regarding the estimation of the erosion-yield relationships, the @RISK program (Palisade Corporation, 1997) is used to estimate probability distributions for the performance criteria. The uncertain parameters are the decline in crop and fodder yield due to soil erosion. As indicated earlier, the extent of productivity loss depends on several factors including rainfall, soil depth, soil type and the slope of the land. Published estimates of rates of soil loss for Ethiopia, which has similar physical characteristics as much of Eritrea, range from 2 percent per annum (SCRP, 1991) to 12 percent per annum (Bojo and Cassells, 1995), and to 21 percent per annum (Sutcliffe, 1993). A triangular distribution is assumed for reductions in crop and fodder yield. The estimates comprise a minimum value, a most likely value and a maximum value. Appendix 2 provides details of the parameter distributions.

5. Empirical Results

Results of the Financial Analysis

The net returns to investment in soil conservation (i.e. the net incremental benefits) are given by the present value of the gross value of output with conservation minus the gross value of output without conservation, less the cost of establishing and maintaining soil conservation structures. It is assumed that other farming costs in the "with" and "without" soil conservation scenarios are the same and therefore the only difference is the cost of undertaking soil conservation measures. The benefits for these two scenarios are discussed below.

Without Soil Conservation Scenario

Outputs for crop and fodder have been estimated for the three slope types. In Year 1, total output per ha ranges from (see Appendix 1) Birr 1863 (Category A) to Birr 1344 (Category B). Without soil conservation, it is assumed that gross farm income will decline as a result of not only a decline in yield but also a decline in total crop area due to the fact that soil depth becomes too shallow to facilitate cultivation. The formula for deriving the decline in crop and fodder yield for this scenario and the parameter assumptions are outlined in Appendix 1. Consequently, output decline per ha will decline at rates ranging from 0.1 to 1.2 percent per annum for the three slope categories.

With Soil Conservation Scenario

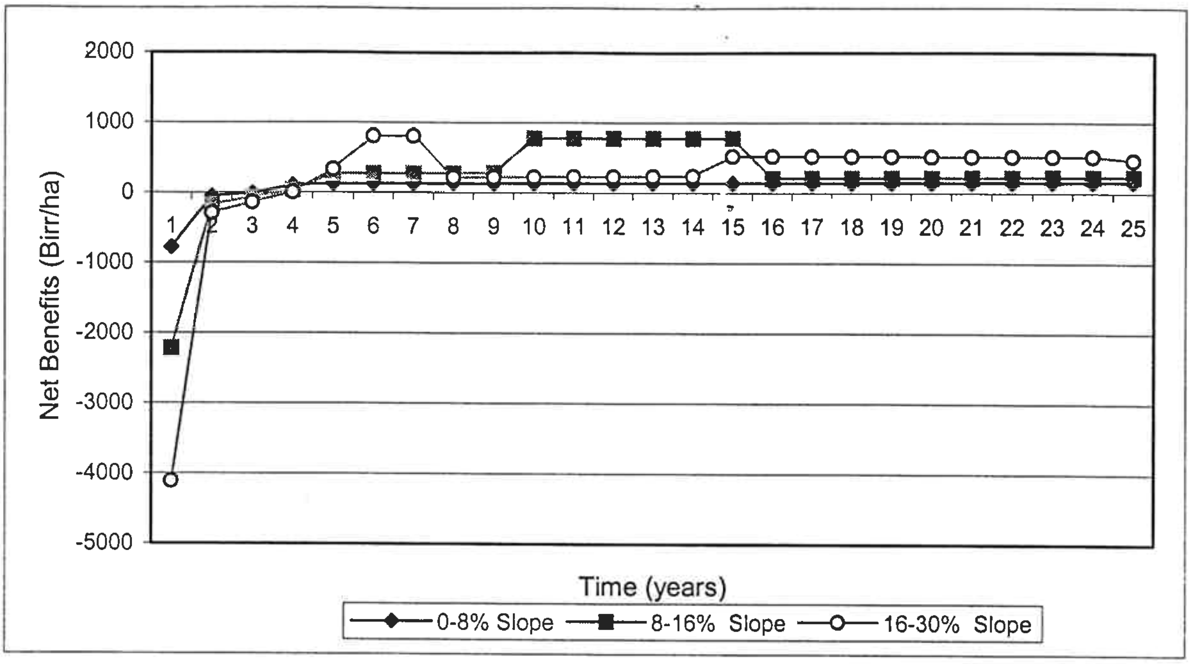
With soil conservation, gross farm income in the first year is expected to be lower than in the without soil conservation scenario due to the fact that the soil conservation structures take away some amount of cropland from production. However, the beneficial effects of the soil conservation measures are assumed to start taking effect after one year. These benefits are phased in as follows: 20 percent in Year 2, and gradually rising to 100 percent by Year 5. The assumptions about the rate of yield increase for this scenario are also detailed in Appendix 1. The soil conservation structures are not 100 percent effective. In other not to overstate the benefits, the structures on Category A land (0-8% slope) are assumed to be 75 percent effective, while those for Category B and C have effectiveness of 50 percent and 45 percent, respectively.

The total value of output per ha with soil conservation in Year 1 ranges from Birr 1813 (Category A) to Birr 1138 (Category C). Total output with conservation is assumed to decline over time at rates ranging from 0.02-0.5 percent per annum. The rate of decline in output on Category C land is expected to be much higher because 37 percent of the cropland will be taken out of production regardless of the conservation measures.

Net Incremental Benefits

It has been assumed that the costs per ha of crop production in the two scenarios are equivalent. It may well be that handling the increased amount of crops and livestock which soil conservation generates will entail higher costs. However, conversely, the decision not to undertake soil conservation also entails higher costs because ploughing eroded land is more difficult and requires greater labour input. In the absence of reliable production costs, such cost differences are assumed to offset each other. Thus, the financial impact of soil conservation measures is taken to be the difference between gross farm income with and without soil conservation less the costs of soil conservation. Figure 1 shows the profile of net financial benefits to investment in soil conservation for the three slope categories. As expected, they are negative in the first year.

Figure 1 Net Incremental Financial Benefits of Investment in Soil Conservation



The net present values and internal rates of return are reported in Table 4. The results are from Monte Carlo simulations using triangular distributions for the yield loss parameters (see Appendix 2) and include means and standard deviations. For all three slope categories, the NPVs are negative and the IRRs are below the cut-off rate of 12 percent. The variability around the mean NPV increases with slope.

Table 4 Financial Returns to Investment in Soil Conservation

Variable/Statistic	Slope Category		
	0 – 8%	8 – 16%	16 – 30%
NPV (Birr/ha)			
Minimum	-613.57	-1238.24	-3302.68
Mean	-18.15	-125.60	-2185.93
Maximum	906.06	726.35	-1037.39
Standard deviation	361.15	426.10	514.61
IRR(%)			
Minimum	-15.4	5.0	2.0
Mean	11.3	11.2	5.0
Maximum	24.1	15.6	8.0
Standard deviation	5.6	2.0	2.0

The foregoing results suggest that, in financial terms, soil conservation becomes less profitable as the slope of the cropland becomes greater. The reason for these differences can be explained as follows. For gently sloping land, soil erosion is not a serious threat to crop productivity. Soil loss and runoff in this case are so low that soil conservation will not dramatically increase yield. On the other hand, for more steeply sloped land, soil erosion is high and therefore the yield response to conservation will be considerable. Nevertheless, the financial returns are negative for the following reasons: 1) as soil conservation structures on steep slopes have to be constructed close to each other, the cost of treating one hectare of cropland is high compared to the cost of treating a hectare of cropland on a gentler slope; and 2) as initial soil loss for this slope category is high, the rate of soil loss will remain high in spite of the erection of soil conservation structures.

Results of the Economic Analysis

The economic analysis takes account of the previous estimates for the rate of soil loss in the Afedyu catchment, the functional relationship between soil loss and crop yield, as well as labour and material costs. As explained earlier, the market prices are adjusted to reflect the social opportunity costs. The net economic benefits of investment in soil conservation are derived in the same way as for the financial analysis. That is, the net incremental benefits are equal to gross farm income with soil conservation minus gross farm income without soil conservation less the economic costs of undertaking soil conservation.

For both Category A and B land net economic benefits are negative in Years 1 to 2 and turn positive in the third year, as illustrated in Figure 2. For Category C land, negative returns are obtained for the first three years. While outputs for Category B and C land commence from a low level, rapid gains in crop productivity are soon achieved. In the case of Category C land, despite the fact that there is a decline in output after Year 7, the net change in output per ha approaches Birr 1000 after 15 years. On the other hand, productivity increase on Category A land is low and only reaches Birr 312 per ha after 25 years.

Figure 2 Net Incremental Economic Benefits of Investment in Soil Conservation

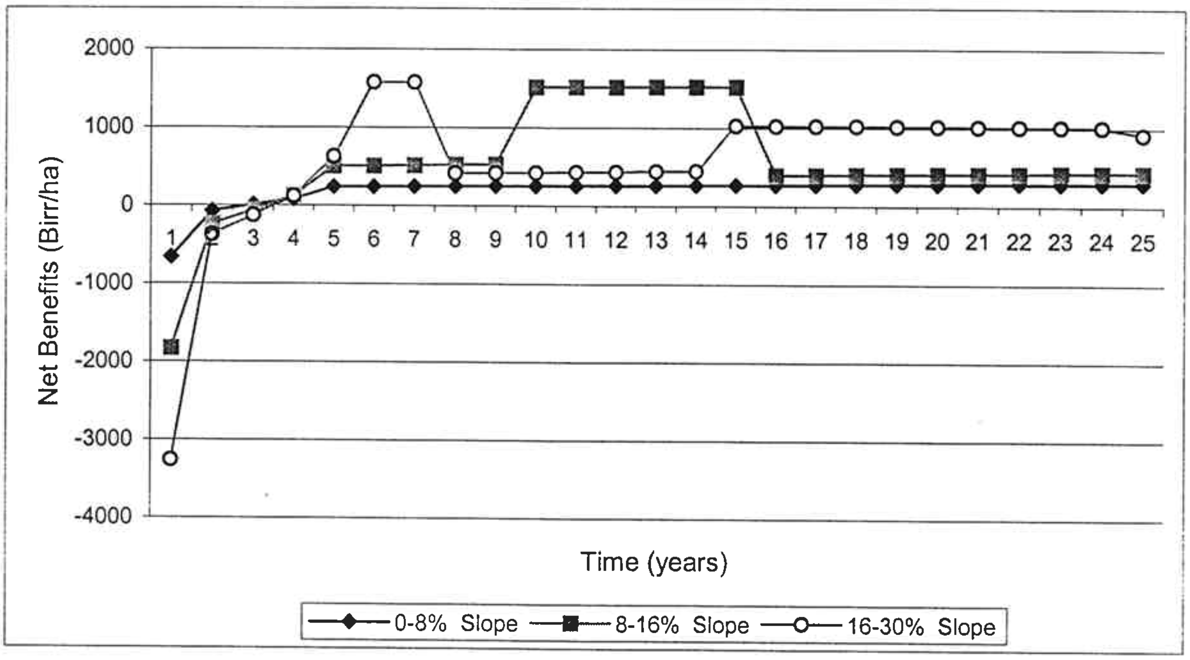


Table 5 reports economic NPVs and IRRs from the Monte Carlo simulations. In contrast to the financial analysis, mean NPVs for all slope categories are positive and the mean IRRs are well above the cut-off rates.

Table 5 Economic Returns to Investment in Soil Conservation

Variable/Statistic	Slope Category		
	0 – 8%	8 – 16%	16 – 30%
NPV (Birr/ha)			
Minimum	-599.92	-240.56	-1539.99
Mean	672.56	2344.34	872.44
Maximum	2623.48	4294.26	3323.14
Standard deviation	756.33	1049.02	1126.21
IRR(%)			
Minimum	9.0	11.0	8.0
Mean	21.0	21.0	14.7
Maximum	43.0	28.0	21.5
Standard deviation	8.0	3.9	3.2

It is important to note that higher returns are achieved on relatively steeper slopes because, among other things, the costs avoided are greater. However, it is also true that on very steep slopes, high costs associated with erecting the conservation structures, as well as relatively high rates of erosion, reduce the net benefits somewhat. In this regard, building conservation structures which are less expensive and more effective in controlling soil erosion and combining these with a change in land use system, could enhance profitability. On the other hand, for Category A land, which is gently sloping and give lower economic returns, the use of alternative measures (e.g. grass planting) could be more profitable.

6. Discussion and Policy Implications

In this section, earlier studies on soil conservation in Ethiopia and other parts of Africa are reviewed and compared to the present study. The section ends with a discussion of the policy implications.

Hurni (1985) estimated the yield effect of soil loss by regressing yield on soil depth using yield data from 50 test plots in the different climatic zones of the Ethiopian highlands. He found that crop yield declined by about 2 percent per annum, equivalent to net soil loss of 42 tonnes per ha per annum. In its Ethiopian Highlands Reclamation Study, the FAO estimated a rate of crop yield decline of 3 percent per annum (Aggrey-Mensah *et al.*, 1984). Recent studies by Sutcliffe (1993) and Bojo and Cassels (1995) show that the earlier estimates were overstated. Sutcliffe estimates an actual yield loss of 0.21 percent per annum, equivalent to a net soil loss of 45 tonnes per ha per annum, while Bojo and Cassels have estimated an actual yield loss of 0.12 percent per annum and net soil loss of 20 tonnes per ha per annum. In this study, estimated yield decline ranges from 0.1-1.2 percent per annum, while soil loss ranges from 7-54 tonnes per ha per annum according to slope type. Our estimates for the yield decline avoided due to soil conservation are more in line with the later Ethiopian studies.

Various studies of the costs and benefits of soil conservation in Africa and elsewhere have reported net economic benefits. Anderson (1987) carried out a cost-benefit analysis of afforestation (shelter belts and farm forestry) in Northern Nigeria. Assuming a rate of decline of 1 percent per annum in soil fertility, he estimated the IRRs to be about 15-17 percent for shelterbelts and 15-22 percent for farm forestry. In an economic evaluation of soil conservation in the Kitui District of Kenya, Holmberg (1990) found that there were higher returns to construction of terraces after taking account of the additional labour requirements and the opportunity cost of capital. The present study focuses on the on-site costs of soil erosion. Although soil removed from one location (i.e. a loss) may be re-deposited in another (i.e. a gain), the net externality effects of soil erosion are likely to be negative. In that regard, the net economic benefits of investing in soil conservation estimated in this study may be regarded as lower bound or conservative estimates of the true benefits.

The results of this study suggest that while investment in simple soil conservation structures such as stone and soil bunds is economically viable from society's point of view but not from the farmer's point of view. Even though positive NPVs are recorded over the planning period, the net benefits are negative for the first two years. Given the subsistence incomes of farmers in the highlands of Eritrea, they cannot afford even temporary income reductions. Thus, farmers are unlikely to undertake soil conservation measures on their own initiative. Furthermore, even if the costs of these structures are publicly provided there is little incentive to maintain them since labour is a major input.

The relatively lower economic returns obtained for steep slopes imply that stone and soil bunds may not be appropriate for all types of slopes. While investment in stone and soil bunds yields positive economic returns for all slope categories, other conservation measures could be more profitable. For example, soil loss from steep croplands remains high even after the construction of soil bunds. Furthermore, to be effective, the bunds on such slopes need to be constructed close to each other, a process that requires greater labour input and takes away more cropland from production. A shift in land use system from crop production to grazing or forestry production in this case could be more effective in controlling soil erosion and could result in higher economic returns. On the other hand, on gently sloping croplands, low-cost soil conservation measures such as contour ploughing could generate higher returns.

The main policy implication of this study is that while the net social benefits of investment in soil conservation technology are positive, farmers have no incentive to adopt it of their own accord due to the financial costs and the long-term nature of the benefits. There is therefore the need for the government to provide incentive mechanisms to encourage farmers to undertake soil conservation. In the past, the main mechanism for achieving this goal was through the FFW programs. However, the record indicates that while this program met an important need of farmers, it was not effective in promoting soil conservation. As indicated earlier, the massive land rehabilitation programs of the mid-eighties to early nineties did not involve farmers and was not based on any socio-economic research.

Research carried out by the authors in the area suggests that the important factors affecting farmers' willingness to undertake soil conservation include perceptions about the profitability of soil conservation measures and the system of land ownership. Farmers who perceive soil conservation to be profitable and those who own their own cropland are more likely to adopt soil conservation measures (Araya and Asafu-Adjaye, 1997). The policy response to the soil erosion problem should therefore include an education program that builds on indigenous environmental conservation knowledge and considers the relative merits of different soil conservation technologies. Preferences of farmers must also be considered in the choice of these technologies. For example, in the study area, most farmers prefer soil bunds to either stone bunds or *fanya-juu*. The latter structures are least preferred because they take too much of the cropping area. The assistance package must be integrated to include other needs such as access to credit to purchase farm inputs and to pay for soil conservation costs and agricultural extension advice. Finally, efforts must be made to deal with the land tenure problem. The issue is more one of guaranteeing security of tenure rather than ownership of land.

Notes

1. In 1988 and early 1999, fierce battles were fought over a disputed strip of territory between the two countries.

2. The use of the USLE over large areas can result in inaccurate results. In this paper, the uncertainty in rates of soil erosion computed from the use of the USLE is handled by using risk analysis techniques to compute the financial and economic returns.

3. Lal (1987, 1994) reports research results on the relationship between soil erosion and productivity; various approaches to measuring soil productivity are contained in Walker (1982); Williams *et al.* (1985), and Bojo (1991).

4. The data from the experimental plots and the details of the soil loss calculations are available from the authors.

5. Assuming one TLU is equivalent to a 250 kg live weight cow (or four 50 kg goats) which requires 6.25 kg of dry matter per day or 2.28 tonnes per annum, one tonne of fodder will support 0.44 TLUs per annum. Assuming each animal needs 3 years to reach the weight of a TLU and that one TLU has a market value of Birr 664, one tonne of fodder is estimated to have an economic value of Birr 99.60.

References

Aggrey-Mensah, W.P., Possio, G., Lakew, K., Adebo, S., and Hagos, Y. (1984). *Degradation of the Ethiopian Highlands and Actions to Combat It: Social and Economic Implications, Costs and Benefits,* Ethiopian Highlands Reclamation Study, land Use Planning and Regulatory Department, Government of Ethiopia and FAO, Addis Ababa.

Anderson, D. (1987). *The Economics of Deforestation: A Case Study of Africa*, The Johns Hopkins University Press, Baltimore.

Araya, B. and Asafu-Adjaye, J. (1997). Adoption of Farm Level Soil Conservation Practices in Eritrea, unpublished manuscript, Department of Economics, The University of Queensland, Brisbane, Australia.

Bojo, J. and Cassells, D. (1995). *Land Degradation and Rehabilitation in Ethiopia: A Reassessment*, World Bank, Paper No.17, USA.

Bojo, J. (1991). *Economics of Land Degradation: Theory and Applications to Lesotho*, Stockholm School of Economics, Stockholm, Sweden.

Ervin, D.E. and Mill, J.W. (1985). Agricultural Land Markets and Soil Erosion: Policy Relevance and Conceptual Issues, *American Journal of Agricultural Economics*, **67(4),** 938-942.

Food and Agriculture Organisation of the United Nations, FAO (1994). *Eritrea Agricultural Sector Review and Project Identification Report*, Rome.

Gardner, K. and Barrows, R. (1985). The Impact of Soil Conservation Investments on Land Prices, *American Journal of Agricultural Economics*, **67(5),** 943-947.

Gittinger J. P. (1982). *Economic Analysis of Agricultural Projects*, The Johns Hopkins University Press, Baltimore.

Goodin, R. (1982). Discounting Discounting, *Journal of Public Policy*, **2,** 53-72.

Hertzler, G., Ibnaz-Meier, C.A. and Jolly, R.W. (1985). User Costs of Soil Erosion and Their Effect on Agricultural Land Prices: Costate Variables and Capitalised Hamiltonians, *American Journal of Agricultural Economics*, **67(5)**, 948-953.

Hoben, A. (1996). The Cultural Construction of Environmental Policy: Paradigms and Politics in Ethiopia, in M. Leach and R. Mearns (eds.), *The Lie of the Land: Challenging Received Wisdom on the African Environment*, James Currey and Heinemann, U.K.

Holmberg, G. (1990). An Economic Evaluation of Soil Conservation in Kitui District Kenya, in J.A. Dixon, D.E. James and P.B. Sherman (eds.), *Dryland Management: Economic Case Studies*, Earthscan, London.

Hurni, H. (1985). *Erosion-Productivity-Conservation Systems in Ethiopia. Paper presented at the Forth International Conservation Conference,* Maracay, Venezuela.

Hurni, H. (1988). Degradation and Conservation of the Resources in the Ethiopian Highlands, *Mountain Research and Development*, **8 (2/3),** 123-130.

International Fund for Agriculture and Development, IFAD, (1986). *Soil and Water Conservation in Sub-Saharan Africa: Issues and Options*, Center for Development Co-operation Services, The Free University of Amsterdam in Co-operation with the Africa Division, Rome.

Krautkraemer, J.A. (1985). Optimal Growth, Resource Amenities, and the Preservation of Natural Environments, *Review of Economic Studies*, **52,** 153-170.

Lal, R. (1987). Effects of Erosion on Crop Productivity, *CRC Critical Reviews in Plant Sciences*, **5 (4),** pp. 303-367.

McConnell K.E. (1983). An Economic Model of Soil Conservation, *American Journal of Agricultural Economics*, **65(1),** 83-89.

Miranowski, J.A. and Hammes, B.D. (1984). Implicit prices of soil characteristics for farmland in Iowa, *American Journal of Agricultural Economics*, **66(5),** 745-749.

Riely, F. (1995). *Addressing Food Insecurity in Eritrea*, Asmara.

Palisade Corporation (1997). *@RISK for Windows Version 3.5e*, Newfield, NY.

Pearce, D. (1987). Foundations of an Ecological Economics, *Ecological Modelling*, 38, 9-18.

Pearce, D. and Markandya, D. (1990). Environmental Sustainability and Cost-Benefit Analysis, *Environment and Planning*, **22**, 1259-1266.

Soil Conservation Research Project (SCRP) (1991). *Eighth Progress Report (Year 1988)*, Vol.9, University of Berne in association with the Ministry of Agriculture, Government of Ethiopia.

Stocking, M. (1996). Soil Erosion: Breaking New Ground, in M. Leach and R. Mearns (eds.), *The Lie of the Land: Challenging Received Wisdom on the African Environment*, James Currey and Heinemann, U.K.

Sutcliffe, J.P. (1993). *Economic Assessment of Land Degradation in the Ethiopian Highlands*: A Case Study, National Conservation Strategy Secretariat, Ministry of Planning and Economic Development, Transitional Government of Ethiopia, Addis Abeba.

Walker, D.J. (1982). A damage function to evaluate erosion control economics, *American Journal of Agricultural Economics,* **64(4),** 690-698.

Williams, J.R., Naney, R.D. and Ahuja, L.R. (1985). Soil Properties and Productivity Changes Along a Slope, *Erosion and Soil Productivity*, ASAE Publication 8-85, St. Joseph, Michigan.

World Bank (1994). *Eritrea: Options and Strategies for Growth, Executive Summary and Main Report*, Vol. 1, Report No. 12390-ER, Washington, D.C.

Yeraswork, A. (1988). Impact and Sustainability of Activities of Rehabilitation of Forest, Grazing and Agricultural lands Supported by World Food Programme Project 2488, report to WFP and to the Natural Resources Main Department, Ministry of Agriculture, Addis Ababa.

Appendix 1a Assumptions for Year 1

Benefits/Costs of Conservation (Birr/ha)	*Slope Category* 0 – 8%	8 – 16%	16-30%
Benefits			
Value of output without conservation:			
Crops[a,b]	1558.11	1377.59	1119.60
Fodder[a,b]	304.77	266.04	224.77
Sub-total	1862.88	1643.63	1344.37
Value of output with conservation:			
Crops[c]	1508.25	1227.43	913.59
Fodder[c]	304.77	266.04	224.77
Sub-total	1813.02	1493.48	1138.36
Change in value of output due to conservation measures:	-49.86	-150.16	-206.01
Costs			
Labour[d]	669.00	2007.00	3846.75
Maintenance[e]	0.00	0.00	0.00
Tools	60.00	60.00	60.00
Total	729.00	2067.00	3906.75
Net returns to conservation measures[f]:	-778.86	-2217.16	-4112.76

a. Yield is 1.67 tons for crops and 3.20 tons per ha for fodder; Prices are: Birr 933.00/ton for crops and Birr 95.24/ton for fodder.

b. Without soil conservation, yield (in tons/ha) in year t is given by: $y_t = [1\text{-}rd/1000y_{t-1}]y_{t-1}$, where: r=depth response; d=rate of decline in soil depth; and y_{t-1} = yield/ha in previous period. Parameter values can be found in Appendix 1b.

c. With soil conservation, output is given by: $ym_t = y_t[1+(ib)]$, where ym_t = yield due to conservation in time t, y_t = yield in time t without conservation (defined above), i = yield increase per annum (%), b = benefits realised (%). Parameter values for i can be found in Appendix 1c. Values for b are 0, 20%, 40%, 60% and 100% in Years 1 to 5.

d. The rural wage is Birr 7.50 per day. Estimates for labour and maintenance can be found in Appendix 1d.

e. Maintenance costs commence from Year 2 and decline by 20% p.a. up to Year 4 and stay constant from then on.

f. Net benefits with conservation increase after Year 1 in accordance with parameter assumptions in footnotes (b) and (c) above.

Appendix 1b Parameter Estimates for Yield, Depth Response and Rate of Decline in Soil Depth

r, depth response: crops = 24; fodder = 73			
	0-8%	8-16%	16-30%
y, yield (for t=1):			
crops	1.67	1.48	1.20
fodder	3.20	2.80	2.36
d, rate of decline in soil depth:	0.07	0.28	0.54

Appendix 1c Parameter Estimates for Yield Increase Per Annum (i) with Conservation (Percentages)

	0-8%	8-16%	16-30%
Crops	0.10	0.34	0.50
Fodder	0.10	0.28	0.38

Appendix 1d Estimates for Labour and maintenance

	0-8%	8-16%	16-30%
Labour (man-days)	89.20	267.60	512.90
Maintenance (Birr)	36.45	103.35	195.34

Appendix 2 Triangular Distributions for Yield Loss Parameters (percent per annum)

Slope category	*Minimum yield loss*	*Mean yield loss*	*Maximum yield loss*
0 - 8%			
Crop yield	0.03	0.05	0.21
Fodder yield	0.03	0.05	0.21
8 - 16%			
Crop yield	0.12	0.41	0.50
Fodder yield	0.12	0.41	0.50
16 - 30%			
Crop yield	0.21	0.50	0.80
Fodder yield	0.21	0.40	0.50

DISCUSSION PAPERS IN ECONOMICS PUBLISHED IN 1999
(A complete list of Discussion Papers in Economics is available upon request.)

251. **Dragun, A.K.,** *Environmental Institutional Design. Can Property Rights Theory Help?*, January 1999.

252. **Jun Wang,** *Entrepreneurship, Institutional Structures and Business Performance of the Overseas Chinese*, March 1999.